PIEZOELECTRIC MEMBRANE ACOUSTIC DEVICES

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ABSTRACT

This paper reports the 3×3×0.003 mm^3 piezoelectric membrane acoustic device, which works as a microphone and a microspeaker. It has a 0.5 µm thick zinc oxide (ZnO) piezoelectric thin film on a 1.5 µm thick low stress silicon nitride membrane, made of LPCVD. The maximum deflection in the center of membrane, using laser Doppler vibrometer, is 1 µm at 7.3 kHz with input drive 15 V_{P-K} (zero-peak). The output sound pressure level (SPL) of microspeaker is 76.3 dB SPL at 7.3 kHz, and 83.1 dB SPL at 13.3 kHz with input drive 15V. The distance between reference microphone and piezoelectric microspeaker is 1 cm. The sensitivity of microphone is 0.51 mV/Pa at 7.3 kHz with noise level of 18 dB SPL.

INTRODUCTION

For last decade acoustic devices have been developed by MEMS technology such as microphone and microspeaker [1-3]. Recently, micromachined acoustic devices are being focused on a lot of applications such as hearing-aid cellular phone, micro-PDA (personal digital assistant) and earphone.

The CMOS-MEMS acoustic devices have the advantage of on-chip electronics, but it require high DC bias volt [4]. Piezolectric microphone and microspeaker [2], which do not have an air-gap, have a more robust fabrication process than do capacitive microphones. The piezoelectric membrane acoustic devices with a silicon nitride thin film have robust fabrication process, but its sensitivity is relatively low and it could not be an output transmitter (microspeaker) [2].

Therefore, some researchers have studied on other types of acoustic devices such as cantilever with a silicon nitride thin film [3], dome-shaped microspeaker with a Parylene thin film [1]. The piezoelectric cantilever microspeaker has a high sensitivity, but the most severe problem arises from residual stress due to dry etching, which prevents working at audio frequency [3]. This paper shows a complete set of experimental results on the piezoelectric membrane microspeaker and microphone with a silicon nitride thin film.

In this paper, we present a piezoelectric microphone and microspeaker fabricated on a bulk micromachined membrane. Figure 1 shows the 3×3×0.003 mm^3 micromachined transducer has a zinc oxide (ZnO) piezoelectric thin film on a 1.5-µm-thick low-stress silicon nitride membrane, made of LPCVD low-stress silicon nitride.

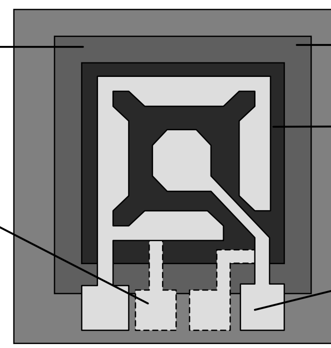


Fig. 1 Schematic view of the piezoelectric membrane acoustic device

DESIGN AND FABRICATION

The first and second vibration modes created at 5.9 kHz and 15.4 kHz by using of finite element simulation (ANSYS). The electrode patterns of the figure 1 are designed based on the distribution of strain. The center aluminum film uses as reflective film of the laser light while the testing of deflection by laser Doppler vibrometer (LDV).

The chief processing is to fabricate a flat, thin, multilayer membrane, and good quality of piezoelectric thin film. Figure 2 shows microfabrication process flow, which has two main parts: 1) membrane formation and multilayer process for piezoelectric acoustic device.

The fabrication starts with 4-in. silicon wafers covered with a 0.2 µm thick thermal oxide. The first 1.5 µm thick LPCVD low-stress silicon nitride layer is deposited on both sides of silicon substrate. Anisotropic etchant (TMAH) is used to release the silicon nitride membrane by etching the silicon wafer from backside.

A 0.4 µm thick aluminum (Al) was deposited as a bottom electrode. A 0.2 µm thick PECVD silicon dioxide (SiO_2) was deposited. Because it need high input impedance to work low frequency range and to use as substrate of ZnO piezoelectric thin film deposition. A 0.5 μm thick layer of ZnO is sputtered onto 0.2 μm thick SiO_2-PECVD. A 0.4 μm thick Al is deposited onto 0.5 μm thick ZnO layer and patterned to form the top electrode. Finally, gold wire is connected with bond pads.

Figure 3 shows the fabricated piezoelectric acoustic device.

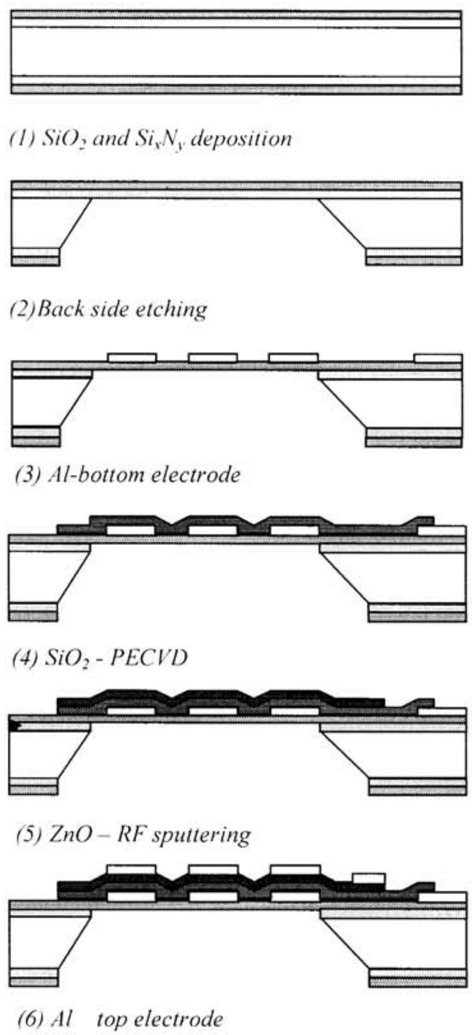


Fig. 2 Microfabrication process flow

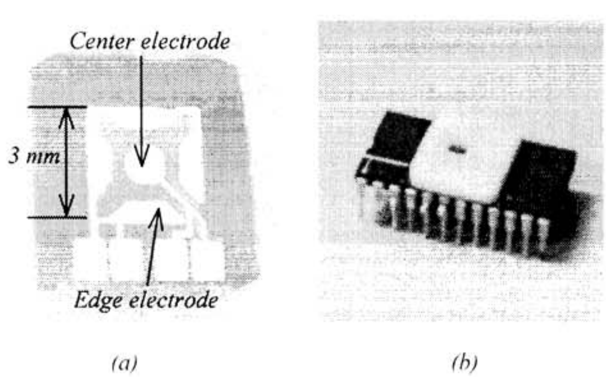
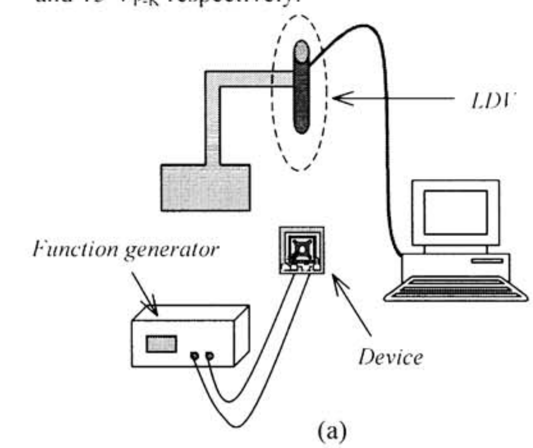


Fig. 3 Picture of (a) a fabricated and (b) a DIP packaged device

EXPERIMENTAL RESULTS

Displacement of Membrane

We measured the deflection in the center of membrane with laser Doppler vibrometer (LDV) from range audio frequency. Figure 4 shows the equipment of LDV. The input drive voltage was 5 V_{P-K} (zero-peak), 10 V_{P-K}, and 15 V_{P-K} respectively.



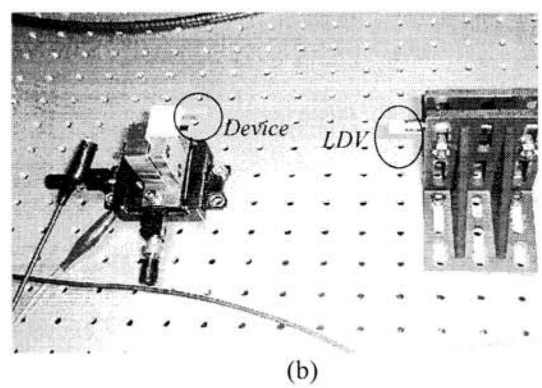


Fig. 4 (a) Schematic view and (b) picture of LDV equipment

Figure 5 shows the characteristic of the displacement at the center of membrane in the audio frequency range. The maximum displacement was 1 μm at resonance frequency 7.3 kHz with driving voltage 15 V_{P-K}.

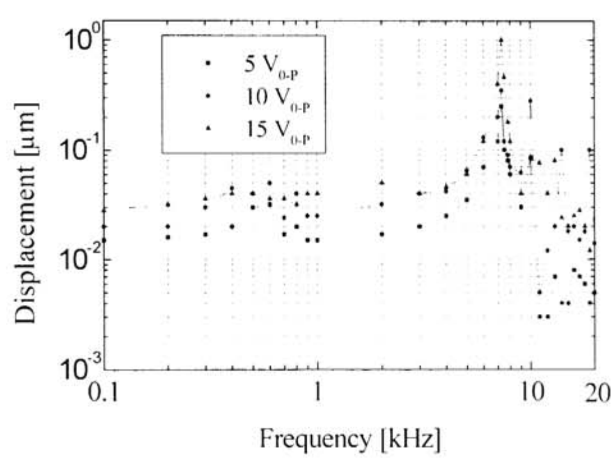


Fig. 5 Displacement at the center of membrane in audible frequency range

Microspeaker Output

We measured the acoustic output of the membrane microspeaker with a calibrated B&K 4190 microphone. Figure 6 shows the sound pressure level (SPL) of piezoelectric microspeaker with input drive of 15 V_{P-K}. The microspeaker SPL output is 76.3 dB SPL at 7.3 kHz and 83.1 dB SPL at 13.3 kHz. Below frequency 4 kHz, output is about 42 dB SPL, edge electrode used for driving electrode of microspeaker as you can see in figure 3 (a). The average reference noise level is 18 dB SPL. The distance between B&K 4190-reference microphone and piezoelectric microspeaker is 1 cm.

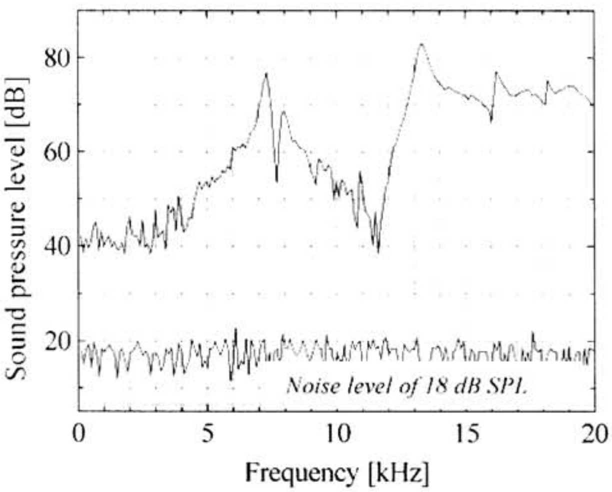


Fig. 6 Microspeaker SPL output with 15 V_{P-K} input drive at a distance of 1 cm

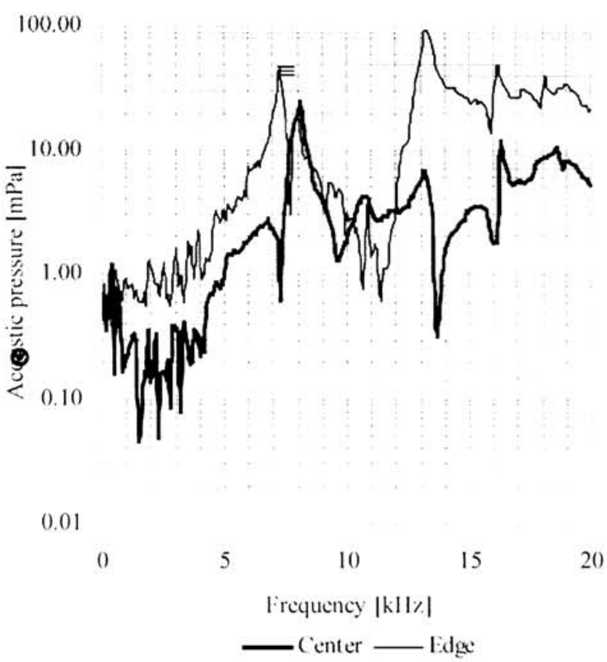


Fig. 7 Microspeaker output acoustic pressure vs. driving electrodes in the audio frequency range with 15 V_{P-K} input drive at a distance of 1 cm

Figure 7 shows sound pressure output vs. sorts of the driving electrodes with input drive 15 V_{P-K}. As you can see in figure 7, edge electrode is higher than center electrode for output acoustic pressure. It results from the strain distribution of the membrane due to acoustic pressure. The output sound pressure is 46.2 mPa at the first resonant frequency 7.3 kHz and 92.8 mPa at the second resonant frequency 13.3 kHz respectively.

Microphone Sensitivity

We tested the characteristic of microphone of the fabricated device. Figure 8 shows the test equipment of microphone. The dynamic moving coil speaker used as an input acoustic pressure source for the fabricated microphone.

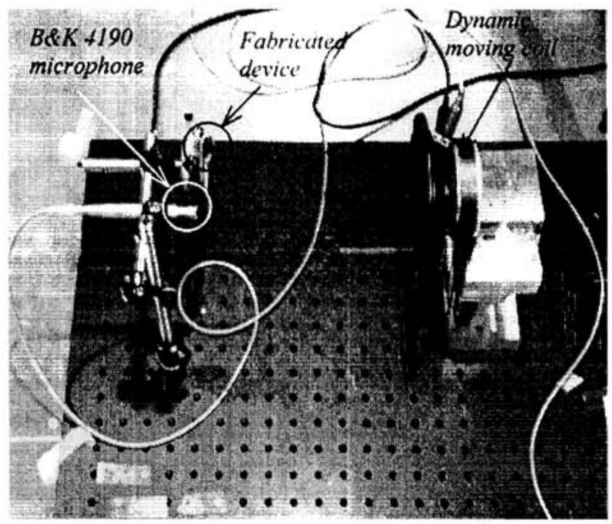


Fig. 8 The test equipment of microphone with input acoustic pressure source of the dynamic coil speaker

Figure 9 shows unamplified output voltage of membrane type microphone. Figure 9 shows the normalized output voltage of the piezoelectric microphone per 1 Pa. Dynamic signal analyzer (Stanford research system) model SR785 was used in the testing of microphone.

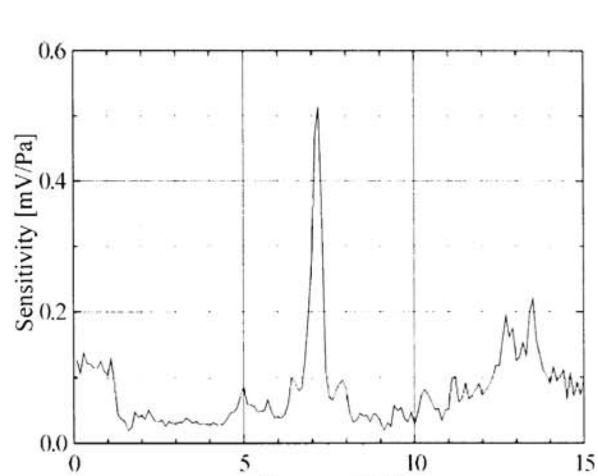


Fig. 9 Unamplified sensitivity of the fabricated microphone in the audio frequency range

At the resonant frequency of 7.3 kHz, the output voltage is 0.51 mV/Pa as you can see in figure 9.

Figure 9 shows the experimental apparatus for microphone test. We tested the function of the microphone using this apparatus as like wire communication. The minimum bias voltage, which works as a microphone, was about 3.5 volts. The gain of the amplifier is 500 in figure 9.

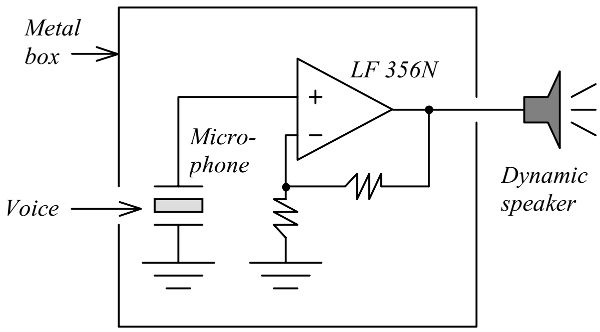


Fig. 9 Block diagram of an experimental apparatus for test of microphone connected with an amplifier

CONCLUSIONS

A piezoelectric micromachined membrane acoustic device was fabricated and tested. The piezoelectric membrane microspeaker with a low-stress silicon nitride membrane realized in this work.

The maximum displacement at the center of membrane using LDV is 1-μm at 7.3 kHz with input drive of 15 V_{P-K}.

The microspeaker output sound pressure level is 76.3 dB SPL at 7.3 kHz and 83.1 dB SPL at 13.3 kHz with input drive 15 V_{P-K} at a distance of 1 cm. The reference noise level is 18 dB SPL.

The maximum sensitivity of the microphone is 0.51 mV/Pa at the first resonant frequency of 7.3 kHz.

ACKNOWLEDGEMENT

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